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# Prevention of Tibetan eco-environmental degradation caused by traditional use of biomass

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ABSTRACT

Tibet is short in fossil energy, but rich in renewable energy sources, such as biomass, hydro, solar, geothermal, and wind power. This potential energy supply in Tibet can be juxtaposed to what drives Tibetan energy consumption its economic motivation and its cultural traditions. Currently, biomass heavily dominates Tibet's energy consumption. In 2003, total energy consumption was about 2 million tce (ton coal equivalent), traditional biomass accounting for nearly 70%. The rarified atmosphere and use of outdated stoves, make for a very low combustion efficiency, utilizing 10–15% of the potential energy of biomass. With population and economic growth, traditional use of biomass has become the principal factor responsible for deforestation, grassland degradation, desertification, and soil erosion. To eradicate the negative impact of the traditional use of biomass on the eco-environment in Tibet, a series of effective countermeasures are investigated. Among these are improved efficiency of stoves, widespread use of solar energy, hydroelectricity as a substitute for traditional biomass, and the development of biogas.



**Contents**



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## 1. Introduction

Traditional use of biomass in the form of firewood, manure, and crop residues is connected to eco-environmental degeneration in many developing countries [1]. Use of biomass is a two edged sword. On the one hand the traditional use of biomass is the main energy supplier for cooking, heating and lighting in rural areas, on the other it intervenes directly into the eco-environment and leads indirectly to eco-environmental degeneration [2–4]. As a case study I examine the case of Tibet in the following.

The Tibetan plateau consist of five Chinese provinces, Xinjian in the North, Qinhai in the North East, Sechuan in the East, Yunnan in the south West, and the Tibet autonomous region (TAR) in the South as shown in Fig. 1. This southern part, with the second largest surface area of any province in China, about 13% of the total (474,300 square miles, about 1.8 times the size of Texas, or 2 times the size of France) borders on India, Nepal, Bhutan, and Myanmar. It has according to the 2005 census a population of 2,675,520 million, 95.3% of which are Tibetan, 3.8% Han Chinese, and the remainder minority groups. About half a million people live in Lhasa its capital. This autonomous region, referred to as Tibet in the following, with an average elevation of more than 4000 m, famous as the "Roof of the world" and the "Third pole of the earth" will be the subject of this study (see Fig. 1).

Tibet special geographical elevation offers a high potential for renewable energies such as solar, wind, hydro geothermal and wind power. On the other hand Tibet lacks fossil fuels such as coal, oil and gas [5,6]. During the many thousands of years of habitation, early evidence placing it at around 10,000 years ago, Tibetan farmers and herdsmen have been relying upon biomass for cooking and heating. Until now, most rural Tibetans still consume biomass energy in its most traditional terms of cattle dung, firewood and crop residue [5].

A wide range of adverse feedbacks on the eco-environment due to the use of biomass can be identified in Tibet among which deforestation, grassland degradation, desertification, soil erosion, and decrease in soil fertility [5–10]. These environmental vitiations, caused by biomass based energy use have not yet become irreversible as is the case for other regions of China. Tibet is however an area of high human-energy-ecology sensibility [8]. It is therefore necessary to have a more succinct insight into the effects of biomass use on Tibetan ecology.

This paper is structured as follows: I shall first give an outline of the energy status of Tibet, the supply side, followed by the current practices as to energy demand. Next I shall review its potential for use of alternative energy supplies, and finally discuss novel initiatives to prevent environmental degradation.

## 2. Energy status of Tibet

### 2.1. Energy supply

Tibet is short in fossil energy but potentially rich in renewable energy as shown in Table 1. Theoretical reserves of coal are less than 50 million tons, and the verified reserve of oil and gas is small [11]. In 2006, the output of coal was below 30,000 tons [12]. Currently, most coal and gas is transported over at least 1000 km from elsewhere by Chuan-Zang Road, Qing-Zang Road, and Xin-Zang Road. About 80% of oil is transported by Golmud-Lhasa pipeline (see Fig. 2). Coal is mainly used in the cement industry, oil for transportation, and gas for cooking.

#### 2.1.1. Biomass

The total biomass energy in Tibet is high, but the per unit resource of biomass low. According to the statistics of 74 counties in Tibet, the total biomass output amounts to $12.82 \times 10^8$ metric tons. Forest accounts for 84.2% and grassland for 15.8% of the total output. However, the average output of biomass is small, 16.357 tons per hectare, equal to 0.2 tce (ton coal equivalent) per hectare in a year [13]. Livestock amounted to 24,380,000 heads in 2006 (7,030,000 heads cattle; 17,030,000 heads sheep; 320,000 heads hogs), producing 40.44 million tons dung, equivalent to 3.64 million tce, 60% being used for heating and 40% as fertilizer [9].

#### 2.1.2. Hydro source

There are many rivers, such as Yarlung Zangbu River, Nu Jinag River, and Lancang River in Tibet with sufficient gradients to make it a very large source for hydropower (see Fig. 3). Reinvestigation of national water resources estimates the gross theoretical hydropower potential and annual average energy generation of Tibet to be 201 GW and 1764 TW h/year, respectively. Tibet's gross theoretical hydropower potential accounts for 29% of the nationwide total, making it in theory the largest hydropower resource in China. The technically exploitable installed capacity and annual average energy generation have been determined approximately as 110 GW and 576 TW h/year. Tibet's technically exploitable installed capacity accounts for 20.3% of the nationwide total, ranking it second to Sichuan Province in China [14].

The current power grid in Tibet is supported mainly by hydropower, with more than four-fifth of power generation coming from hydroelectricity. In 2004, the total installed generating capacity of Tibet reached 469 MW, including 404 MW of hydropower. Power generation in Tibet reached 1206 GW h in 2004, of which 1088 GW h was hydropower [15].

#### 2.1.3. Solar energy

The potential for utilizing solar energy is large in Tibet (see Fig. 4). With an average altitude over 4000 m, Tibet's annual average sunshine hours fluctuates around 3000, with an average of 250 h monthly and a monthly range between 220 and 280, ranking it first in China [16]. The high altitude rarified atmosphere and low relative humidity make for extremely intense sunlight, with an average annual radiation intensity of 6000–8000 MJ/m$^2$, ranking it second worldwide after the Sahara [17]. Tibet is first in China in photovoltaic solar power generation. Statistics show that 400 solar power plants with generating capacities of 10–100 kW have been built in Tibet, providing nearly 9 MW in electricity by the end of 2007 [18,19].

**Table 1**
Energy resources in Tibet.

| Type | | Resources assessment |
|---|---|---|
| Fossil energy | Oil and coal | The theoretical reserves of coal resources are less than 50 million tons. Oil resources not yet clear. |
| Renewable energy | Biomass | The total output of biomass reaches to $12.82 \times 10^8$ tons, which equal to 24 million tons tce/a. However, the average productivity of biomass resources is small (0.2 tce per ha in a year). |
| | Hydropower | The technically exploitable installed capacity and annual average energy generation have been determined approximately as 110 GW and 576 TW h/year, respectively. |
| | Solar energy | Average annual radiation intensity reaches 6000–8000 MJ/m$^2$ in Tibet. |
| | Geothermal | The geothermal energy totals to $2.871 \times 108$ kJ/S, equivalent to 3 million tce/year, generation power potential of 800 MW. |
| | Wind power | Wind energy resources in Tibet total about 7730 kW. |




**Fig. 1.** The location of the study area (population density from http://www.gdnet.org/CMS/conference/presentations/Gang%20Liu.ppt).

*2.1.4. Geothermal*

Tibet has nearly 600 thermal features, including thermal springs, thermal wells and mine outflows. Based on the statistics of 350 of them, geothermal energy totals $2.871 \times 10^8$ kJ/S, equivalent to 3 million tce/year, a generating power potential of 800 MW, accounting for 80% of China's total. Yangbajing (see Fig. 2) in Tibet is the largest geothermal power plant complex in China. Its total capacity is 25.18 MW (gross), 16 MW (net), generated by nine single flash, double flash, and hybrid cycle power plants, fueled by 140–160 °C fluids flowing from 18 wells, approximately 200 m deep. This plant supplies 41% of the power needed by Lhasa City in summer and 60% of its winter needs [20].

*2.1.5. Wind power*

Energy generated by wind in Tibet totals about 7730 kW. Generators are centered into two windy belts: the northern section between Agari prefecture and Ngari prefecture, and the eastern section between the Himalayas and Mount Kailash as shown in Fig. 2. Outside these two regions, the average speed of wind is below 5.0 m/s, i.e. insufficient for sustained wind power genera-

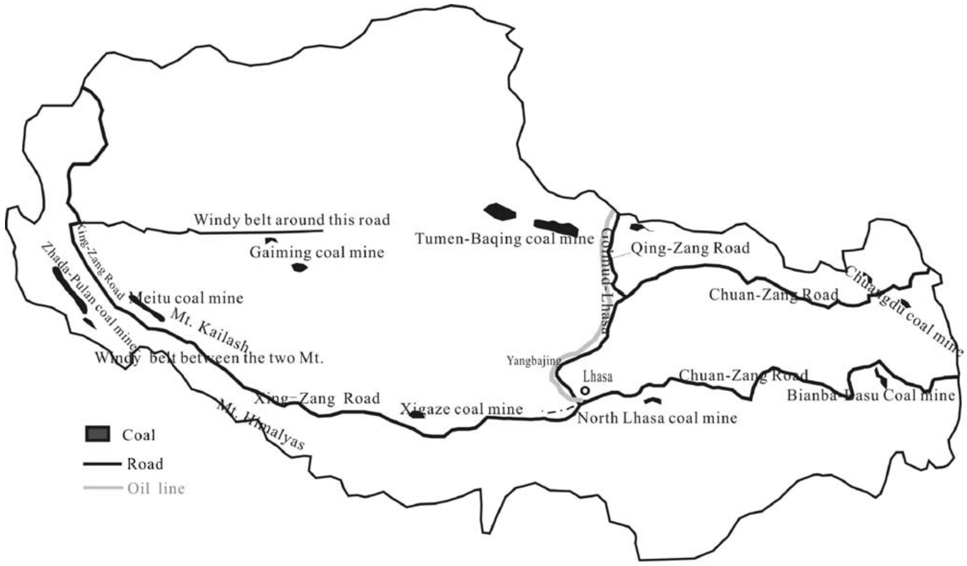



**Fig. 2.** Coal, energy transportation line (gas lines are under construction) and majority wind belts in Tibet, China (from http://www.mysteel.com/ll/meitanzhishi/2008/02/19/110903,0306,0,1726061.html).

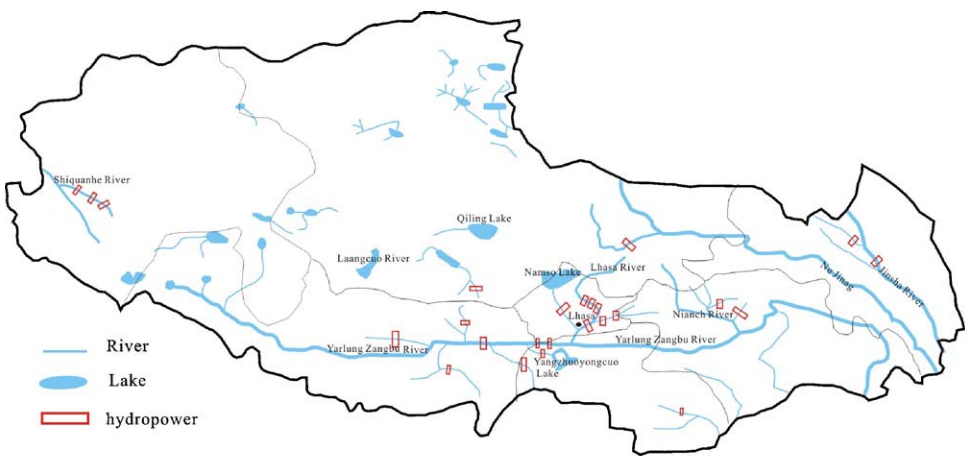



**Fig. 3.** Hydro sources in Tibet, China (from www.rsscity.com.cn/Scenic/346/detail6316.html).

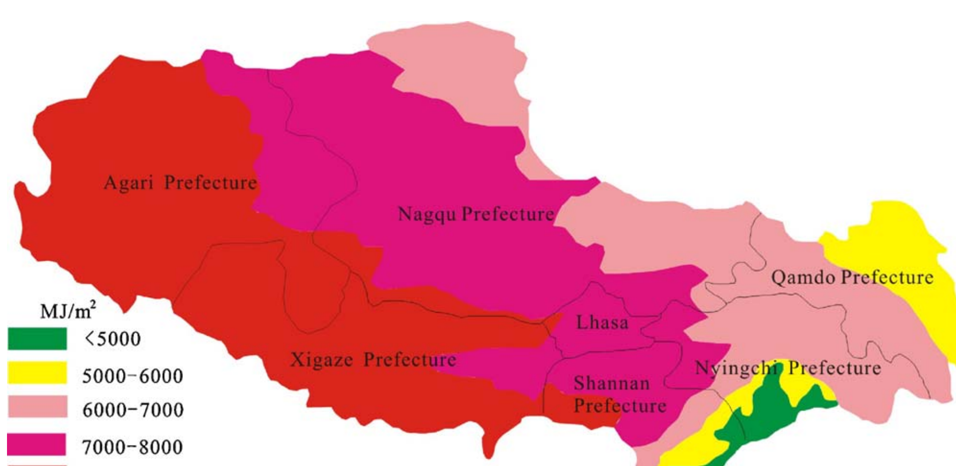



**Fig. 4.** The distribution of solar energy in Tibet, China (from www.weatherinfo.com.cn/zy/gnzy.html).



**Fig. 5.** Photo showing (A) dung dry in grassland. (B) Tibetan traditional wedding mascot—cattle dung. (C) Cattle dung sold in Lhasa street [24,25].

tion. This lack of wind, aggravated by the low air density makes Tibet's wind power supplementary to other energies [21]. For example, Tibet's government has built in collaboration with the Institute of Electrical Engineering, Chinese Academy of Sciences, China's first wind–solar hybrid power system with capacity of 4 kW located in Zhayi Township in 1998 [22]. A total of 10 wind–solar power systems have been set up during the "*Rural electrication*" project [18].

### 2.2. Energy consumption

Having looked at Tibet's natural resources and their potential in providing energy, I want now to turn to the principal driving forces for energy consumption in Tibet.

#### 2.2.1. Economic reasons

Manufacturing industry only accounts for one-fourth of the total gross development product in Tibet. Accordingly, energy is mainly used for livelihood and household, seventy present of the total electricity supply is consumed by livelihood and households whereas 20% is used by industry and 10% is unspecified. Livelihood and household energy consumption in rural areas may reach over 80% of the total energy consumption, whereas enterprises in townships consume less than 20% [5,23].

#### 2.2.2. Cultural tradition

Tradition is a very important factor in energy consumption in Tibet. For example, cattle dung is an indispensable material in Tibetan weddings, funerals, major festivals, worship, and treatment of certain diseases [24,25] (see Fig. 5). Cattle dung accounts for about 53% of Tibet's rural total energy consumption today [9]. Farmers and herdsmen in Tibet have been relying upon this traditional biomass, besides firewood and crop straw, for cooking and heating for thousands of years. Many people, especially farmers and herdsmen continue to use biotic energy as their fuel of choice. In 2003, the total amount of energy consumption was about 2 million tce, of which traditional biomass accounted for nearly 70% [26,27]. Most of the biomass is directly burned as fuel for cooking and warming.

## 3. Eco-environmental problems caused by biotic resource use

The rarified atmosphere and use of inefficient stoves, result in a very low burning efficiency, utilizing 10–15% of the potential energy of biomass [9,28]. With population and economic growth, biotic energy sources are being overused, and excessive depletion of biotic energy sources has become a main factor responsible for deforestation, grassland degradation, desertification and soil erosion in Tibet.

### 3.1. Deforestation

The forested area in TAR per capita is more than 18 times the average in China, per capita wood production in Tibet is more than 78 times the average in China. This seeming abundance does not imply that fuel wood is a sustainable resource because the percentage of vegetation cover is only 37.8% of the average cover in China [29] (see Table 2). Fuel wood gathering and

**Table 2**
Tibet autonomous region forest resource [29].

| Name | Forest areas (ha) | Per capita forest areas (ha) | Wood production ($m^3$) | Per capita wood production ($m^3$) | Percentage of vegetation cover (%) |
|---|---|---|---|---|---|
| China | $2.28 \times 10^8$ | 0.175 | $139.61 \times 10^8$ | 10.69 | 18.21 |
| TAR | $844.5 \times 10^6$ | 3.13 | $22.66 \times 10^8$ | 839.26 | 6.88 |
| TAR/China (total) | 3.70 | | 16.23 | | 37.78 |
| TAR/China (per capita) | | 17.89 | | 78.51 | |

**Table 3**
Soil erosion in Tibet [39].

| Soil erosion type | Area of soil erosion | | Soil erosion intensity | | | |
|---|---|---|---|---|---|---|
| | | | Mild | | More than middle | |
| | Area of soil erosion | Area of soil erosion/total area | Area of soil erosion | Area of soil erosion/ total area | Area of soil erosion | Area of soil erosion/total area |
| Water erosion | 62,056 | 5.05% | 58,679 | 4.78% | 3,377 | 0.27% |
| Wind erosion | 50,592 | 4.12% | 44,313 | 3.61% | 6,279 | 0.51% |
| Erosion of thawing soil | 921,580 | 75.02% | 389,663 | 31.72% | 531,917 | 43.30% |
| Total erosion | 1,034,228 | 84.19% | 492,655 | 40.11% | 541,573 | 44.08% |

burning, occurring in forested and non-forested areas, is the largest use of wood in Tibet. A family uses annually 5–6 tons wood for cooking and heating, the equivalent of 6–7 cubic meters of timber, causing the loss of around 0.3 ha of forest per year. Statistics indicate that Tibet's wood consumption for fuel has passed 3000 million cubic meters over the last 30 years, 6 times more than commodity wood consumption. Moreover, fuel wood consumption and concomitant deforestation have been spurred by lack of systematic forest management, unclear boundaries between natural and planted forest, and inadequate management resources leading to arbitrary and indiscriminately felling of trees [9].

### 3.2. Grassland degradation

Grassland occupies about $8.2 \times 10^8$ ha, and constitutes two-thirds of Tibet's area. For pasture $5.6 \times 10^8$ ha is available, 68% of the total grassland area [30]. The main types of vegetation distributed in the Tibet are alpine cold meadow, steppe meadow, and alpine cold steppe.

Cattle dung collection and consumption results in decreased soil fertility and is blamed for soil and grassland degradation. Owing to the influence of high-cold climate, high-cold meadow, soil exhibit significant peat accumulation but decomposition and mummification of organic matter are slow. These peat lands are fertile but their nutrient absorbance is poor. Lack of nitrogen and phosphorus affects grass growth during the growing season. Nitrogen loss caused by animal grazing is normally compensated by animal dung through microbial decomposition and rainwater leaching, maintaining the soil nutrition balance. Collecting cattle dung removes a source of nitrogen from this environment causing a reduction in soil fertility and thus promotes grassland degradation [8,31]. Organic matter content and total nitrogen content were more than 5% and more than 0.2%, respectively in Tibet's soil in the 1960s [32]. In 2004, both organic matters and total nitrogen content decreased to 0.5% and 0.10%, respectively [33], with concomitant degradation of grassland. For example, the area of degraded grassland increased from $1.2 \times 10^8$ ha in 1989 to $4.3 \times 10^8$ ha in 2002, or about 240% [34]. Such grassland degradation directly impairs the grassland ecosystem function such as regulating climate, preventing water run off, conserving soil, grass production and biodiversity.

### 3.3. Exacerbation of desertification

The harsh climatically conditions make Tibet sensitive to desertification, severely retarding vegetative restoration [35]. From 1999 to 2004, the desertified area expanded by 64,725 $km^2$, about twice the size of Taiwan, or the combined surface area of the Netherlands and Belgium [36]. Use of traditional biomass has aggravated desertification.

Shrubs, such as *Sophora moorcroftiana*, *Hippophae Rhamnoides* and *Sabina procumbens* are extremely important in preventing desertification. For example, *Sophora moorcroftiana*, an endemic leguminous shrub in Tibet, is found in valleys, slopes, terraces. *Sophora moorcroftiana* not only merely tolerates sand burial, but actually responds positively to sand accumulation. *Sophora moorcroftiana* is regarded as an ideal species in preventing desertification [37]. Wind tunnel experiments showed that in 10 or 15 min of blowing at a specific speed, the soil surface remained undisturbed with complete *Sophora moorcroftiana* vegetation, eroding about 0.34 kg of soil. In contrast 1.46 kg of soil was deflated when 30% of the vegetation was cut down, and 4.68 kg when 60% of the vegetation was cut down. In the absence of vegetation, 9.12 kg of soil was deflated [8].

However, shrubs became farmers' and herdsmen's most widely used fuel source in Tibet's forest-free areas. In autumn farmers and herdsmen dig up and store large amount of shrubs for cooking and heating in winter. Residential areas are therefore almost devoid of shrubs [8]. Moreover, grubbing out shrub makes root propagation impossible which is substantially more effective as growth from seeds requiring for *Sophora moorcroftiana* 4 years to reach 50 cm height [38].

### 3.4. Aggravated soil erosion

The 4-km-high Tibetan plateau is an outstanding topographic feature on the Earth. Its horizontal extent, elevation, and location make Tibet's land sensitive to soil erosion. Area of soil erosion of Tibet is 1,034,200 $km^2$, accounting for 84.19% of total area [39] (see Table 3).

Use of traditional biomass has accelerated soil erosion, especially in the Yijianglianghe Region (midstream area of the Yarlung Zangbo River, Lhasa River and Nianchu River) which is Tibet's economical and population center (see Fig. 2). Since 1970s, the Yijianglianghe Region has been gradually evolved into the most serious area of soil erosion in Tibet. At present, soil erosion affects 74% of this region [40]. A percentage of vegetative cover is only 5% at some of its districts in the Yijianglianghe Region. Most vegetation is herbaceous and shrub, such as *Sophora viciifolia*, *Pennisetum*, *Stipa purpurea* and small between 5 and 50 cm in height. However, a survey shows that the average annual collection per capita is 200–300 kg of *Sophora viciifolia*, which is equivalent to output of *Sophora viciifolia* of 0.07–1.33 ha. It is estimated that nearly 0.40–0.67 million hectare of natural shrub and forest have been logged for fuel each year in the Yijianglianghe Region. The expansion of bare areas as a result of vegetation damage has accelerated soil erosion [41].

## 4. Countermeasures

Multilevel countermeasures must be adopted to eradicate the use of traditional biomass and its associated negative impact on the eco-environment including investment in improved stove efficiency, solar energy, wind electricity, and biogas. These counter measures I shall discuss in the following (see Table 4).

**Table 4**
Countermeasures to combat use of traditional biomass negative impact on eco-environment in Tibet.

| Project | Brief introduction |
|---|---|
| Improve stove efficiency | The efficiency of traditional use of biomass stove is less than 15%. So there is a great potential to improve the energy efficiency by design better biomass-burning stove. |
| Use of solar energy | Up to end of 2007, the number of solar stoves is 26 million, solar energy-heated greenhouses and passive solar building totaling reach to nearly 3 million square meters up to end of 2007. |
| Hydroelectricity substitute for traditional biomass | Tibet has rich in hydropower resources. Hydropower, especially small hydropower has a great potential substitute for traditional biomass. |
| Great potential of household biogas plant | 250,000 digesters constructions will be completed and the marsh gas are popularly used by 1,250,000 farmers and herdsmen during 2006–2010. |

### *4.1. Improved stove efficiency*

As mentioned above, the fuel efficiency of a traditional biomass stove for boiling and cooking is not more than 15% in Tibet. Here substantial gains may be made by designing better biomass-burning stoves with advanced combustion techniques. For example, the traditional burning of dung is a smoky and inefficient process. However, a better dung-burning stove designed by Aprovecho Research Center in Creswell Oregon, United States has demonstrated that dung can, in fact, be burned cleanly and efficiently [42] (see Fig. 6), the trick being on the one hand to increase the combustion temperature and thus decrease smoke emanation, on the other improved heat exchange in the exchange part. As another example, Liu et al. have shown in an outdoor experiment in Taktse, Tibet that a traditional stove, about 35 cm in diameter, needs 30–40 min to boil a pot of water (boiling point 86 °C at 4000 m), whereas new energy-saving iron stove, about 20 cm in diameter, needs only 15–20 min to boil a pot of water [27]. There is clearly substantial room for improvement in this in principle simple endeavor to reduce emission of harmful pollutants together with a substantial reduction in fuel use.

### *4.2. Use of solar energy*

Solar thermal utilization is a key to reduce the use of traditional biomass as Tibet is rich in solar resources. Solar thermal applications include cooking, heating and cooling of buildings, and heating water. Such technologies are comparatively simple, relatively cheap and easy to adopt [8,18,27].

Cooking with the sun has become a viable substitute for traditional biomass burning in food preparation in Tibet (see Fig. 7). A number of public sector organizations, such as the Tibetan Energy Research Center have worked in the past and are still working on the development of low cost and efficient designs of both box and concentrator type solar cookers. The number of solar stoves in Tibet reached 26,000 by the end of 2007. A solar stove boils 3.8 kg of water in 15 min under regular sunshine. It is estimated that a single solar cooker saves 1000 kg of firewood per household annually [27]. Future plans are to develop, a portable, lightweight, foldable and low-cost solar stove to increase the popularity of solar stoves.

Tibet particularly needs to utilize the sun, as in solar energy-heated greenhouses or passive solar building because Tibet belongs to the “Cold Region” in China [43] and energy consumption for heating is very large in the winter. Passive solar buildings aim to maintain interior thermal comfort throughout the sun’s daily and annual cycles whilst reducing the requirement for active heating and cooling systems. Passive solar buildings can provide an indoor thermal environment in winter without consuming fossil fuel without causing overheating in summer. Such buildings have been constructed in the Ngari and Nagqu counties of Tibet in the 1990s. At the end of 2007, Tibet had built 3 million square meters of solar energy-heated greenhouses and passive solar buildings [27]. In 2007, an experiment was carried out by the Tibetan Energy Research Center combining passive solar building and other insulation technologies in some schools. These experiments showed that this technology can make the indoor warmer vis a vis outdoor by at least 10 °C, basically meeting winter heating requirements, with an additional construction cost of about 20%.

### *4.3. Hydroelectricity substitute for traditional biomass*

As mentioned above, there are many rivers in Tibet well suited for generating hydroelectricity. Hydropower, especially small hydropower in Tibet is potentially a great substitute for traditional biomass burning. Fortunately, Tibet’s government has recognized this potential. During the “11th Five-Year” (2006–2010), Tibet’s giant hydropower projects include the Xueka hydropower station with 40 MW of installed capacity and investment 700 million Yuan (US$ 103 million) the Tiger Mouth hydropower station with 100 MW of installed capacity (Tibet’s largest single hydroelectric generator) and investment 1.29 billion yuan (US$ 190 million), the Yajiangzangmu hydropower station, and the Lasazhaxue hydropower station [44]. Next to these large and expensive

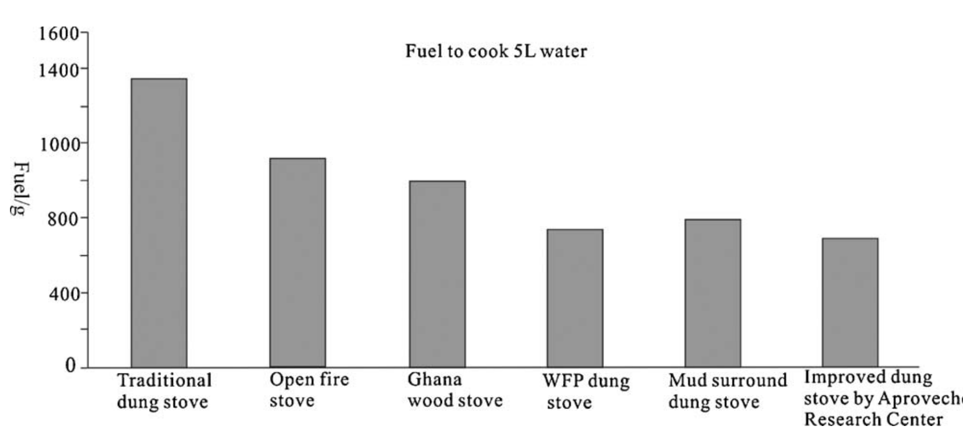



**Fig. 6.** Comparison of dung stove to wood-fueled stoves for fuel used [42].




**Fig. 7.** Photo showing solar stove in Tibet (from http://www.sjzsme.gov.cn/sme/servlet/com.stencil.BrowseDoc?docNo=1122; http://www.aaf.cc/?action-viewnews-itemid-296; http://news.xinhuanet.com/politics/2006-09/11/content_5078145.htm; and http://zt.tibet.cn/t/2005focus1/200502005916110425.htm).

projects, there are also several smaller hydroelectric plants in Tibet. According to the latest planning, small hydropower installed capacity of 139,000 kW will be constructed in rural Tibet. The small hydropower stations will be distributed in 35 counties, giving 32 counties with 420,000 people for the first time access to electricity [9].

### 4.4. Great potential of household biogas plant

Development of household biogas also shows substantial promise in Tibet. In many other rural regions of China, biogas in small single units of biogas plants per household have been used successfully for many years [45]. The climate of a region plays a key role in making biogas plants economically feasible. The high solar radiation in Tibet can be used to broil organic material from animal, plants, and human waste. Neighboring Nepal has shown how the installation of biogas plants helped reduce the use of traditional biomass enormously during the past 30 years [46].

During the "10th Five-Year-Plan" (2000–2005) period, Tibet began to test, demonstrate and promote the use of biogas in different regions, different climates, and ecological environments. In 2006, treasury bonds of Tibet's rural project of biogas construction were launched officially. After a 10 year effort by the Tibetan government, construction of 250,000 digesters was completed and use of this marsh gas became popular by 1,250,000 farmers and herdsmen, during the "11th Five-Year-Plan" (2006–2010) period. This new type of energy-efficient gas model project could increase the annual savings for a farmer or herdsman household by 4000 yuan (US$ 597) and save 2500 kg firewood or 4000 kg cow dung, as estimated by the Office of Farmers and Herdsmen in Tibet [47]. In the long-term, biogas like gas or LPG can be used for cooking, boiling and lighting and even for generating electrical power.

## 5. Conclusion

As Tibet's economy advances it requires more energy. The traditional use of biomass and its negative impact on the eco-environment has become an ever-more serious challenge. Given Tibet's peculiar environment and valuable ecosystem, it is extremely important to eradicate the use of traditional biomass because of its negative impact on the eco-environment. Fortunately, a series of effective countermeasures may be adopted, such as improved efficiency of stove, widespread use of the solar energy, hydroelectricity substitute for traditional biomass, and development of biogas. These countermeasures will play an important role in the harmonious coexistence of humans and their environment as well as for the sustainable development in the future.

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## References


[1] Ravindranath NH, Hall DO. Biomass, energy, and environment: a developing country perspective from India. Oxford: Oxford University Press; 1995.

[2] Sagar AD. Alleviating energy poverty for the world's poor. Energy Policy 2005;33(11):1367–72.

[3] Akella AK, Sharma MP, Saini RP. Optimum utilization of renewable energy sources in a remote area. Renewable and Sustainable Energy Reviews 2007; 11(5):894–908.

[4] Gupta CL. Role of renewable energy technologies in generating sustainable livelihoods. Renewable and Sustainable Energy Reviews 2003;7(2):155–74.

[5] Cai J, Zhang L. Status and prospect of use energy in Tibet. Energy of China 2006;28(1):38–42. in Chinese with English abstract.

[6] Wang Y-q, Basang L, Yang Y-j. Thinking over adjustment of energy structure in Tibet. Central South Forest Inventory and Planning 2007;26(1):60–3. in Chinese with English abstract.

[7] Zhang J-p, Zhen X-h, Zou X-y, Jin H-l. The eco-environmental problems and its countermeasures in Tibet. Journal of Mountain Science 2001;19(1):81–6. in Chinese with English abstract.

[8] Wei X-h, Yang P, Wang Y-j, Xie Z-k. Use of rural energy resources and eco-environmental degradation in Tibet. Journal of Environmental Sciences 2004;16(6):1046–50.

[9] Government of Tibet Autonomous Region of China. Firewood alternative energy development planning in Tibet autonomous region. Lhasa: Government of Tibet Autonomous Region PR China; 2008.

[10] Xu Z-r, Cheng S-k, Min Q-w, Zou X-p. An evaluation on basis of resource and environment for developing bio-energy in Tibet. Journal of Natural Resources 2007;22(2):243–50. in Chinese.

[11] National Energy Bureau of China. Energy condition and development in Tibet. Beijing: National Energy Bureau of China; 2006, in Chinese.

[12] China energy statistical yearbook-2007. Beijing: Department of Industry and Transport Statistics, National Bureau of Statistics and Energy Bureau, National Development and Reform Commission of China; 2007.

[13] Xu Z-r, Cheng S-k, Min Q-w, Zou X-p. An evaluation on the basis of resource and environment for developing bio-energy in Tibet. Journal of Natural Resources 2007;22(2):243–50. in Chinese with English abstract.

[14] Wang M, Guo X, Guo J. Research on hydropower and economic development of the Tibetan autonomous region. Water Power 2006;32(12):1–4. in Chinese.

[15] China electric power yearbook-2005. Beijing: China Electric Power Press; 2005

[16] Wang Y-q, Basang L, Yang Y-j. Thinking over adjustment of energy structure in Tibet. Central South Forestry Inventory and Planning 2007;126(1):60–3. in Chinese.

[17] Wang Y-q, Wang J-l. Tibet solar energy develop existing problem and several suggestions. Tibet's Science and Technology 2007;166(2):26–8. in Chinese.

[18] Cai G-t, Zhang L. Research on Tibet rural energy consumption and its environmental impact. Resource Development & Market 2006;22(3):238–41. in Chinese with English abstract.

[19] People's Daily, Tibet leads nation in solar energy development. People's Daily, 2006-11-27, or available from: http://nc.people.com.cn/GB/61156/61926/5090537.html, in Chinese.

[20] Xie E. Study the development of Tibet's geothermal energy. Tibet's Science and Technology 2002;107(2):61–72. in Chinese with English abstract.

[21] Zhang H, Ge S, Lu H. Primary analysis and evaluation of wind power in Tibet. Tibet's Science and Technology 2005;143(3):33–4. in Chinese with English abstract.

[22] Li P, Xu H-h, Liu G-q. Development of 4 kW wind/PV hybrid generation system in Tibet, China. New Energy Sources 1998;20(10):10–3. in Chinese.

[23] Tibet statistical yearbook-2007. Lhasa: Tibet Autonomous Bureau of Statistics and Tibet General Team of Investigation under the NBS; 2007, in Chinese.

[24] Ge E. Tibet's culture of cattle dung. Tibetan Folklore 2003;(1):44–7. in Chinese with English abstract.

[25] Zhang X. Tibet's tradition of cattle dung. China's Tibet 2004;(2):63–5. in Chinese.

[26] Zhou S, Zhang X. Prospect of briquetting biomass fuel by forest residues in Tibet. Korean Journal of Chemical Engineering 2007;24:170–4.

[27] Liu G, Lucas M, Shen L. Rural household energy consumption and its impacts on eco-environment in Tibet: taking Taktse county as an example. Renewable and Sustainable Energy Reviews 2008;12(7):1890–908.

[28] Li J, Hu R, Song Y, Shi J, Bhattacharya S, Salam A. Assessment of sustainable energy potential of non-plantation biomass resources in China. Biomass and Bioenergy 2005;29(3):167–77.

[29] State Forestry Administration of China. China forestry statistical yearbook-2006. Beijing: Chinese Forestry Press; 2006.

[30] Shao W, Cai X. Grassland degradation and its formation causes analysis in Tibetan plateau. Science of Soil and Water Conservation 2008;6(1):112–6. in Chinese with English abstract.

[31] Zhang T. Relations between energy resources and grassland eco-environment in pastoral areas of Tibet. Ecology and Natural Conservation 2001;(2):36–7. in Chinese with English abstract.

[32] Guan S. The relationship between eco-environmental conditions, natural disasters and soil nutrient. Tibet Journal of Agricultural Sciences 1990;(3–4):51–4. in Chinese.

[33] Zhong G-h, Tian F-y, Wang M, Zhang H-f, Liu G-h, Ci B. Soil fertility of croplands in major agricultural areas of Tibet. Soil 2005;37(5):523–9. in Chinese with English abstract.

[34] CPPCC. Report about grassland protection and development in Tibet autonomous region. Beijing: General Office, National Committee, Chinese People's Political Consultative Conference; 2003.

[35] Yang H, Lu Q, Wu B, Zhang J, Lin Y. Vegetation diversity and its application in sandy desert revegetation on Tibetan Plateau. Journal of Arid Environments 2006;65(4):619–31. in Chinese with English abstract.

[36] Wang X-y, Xu Z-g. Study on the dynamic changes of desertification in Tibet. Research of Soil and Water Conservation 2007;14(6):47–50. in Chinese with English abstract.

[37] Zhao W, Zhang Z, Li Q. Growth and reproduction of *Sophora moorcroftiana* responding to altitude and sand burial in the middle Tibet. Environmental Geology 2007;53(1):11–7.

[38] Li S, Zhao W. Study on sand vegetation in bottom of middle reaches of Yarlung zangbo River in Tibet. Journal of Desert Research 1994;14(1):68–74. in Chinese with English abstract.

[39] Tibet soil and water conservation. http://www.xzsbw.gov.cn/, in Chinese.

[40] Cai X-b. Characteristics of soil degradation of the "Yijianglianghe Region" Tibet. Soil and Fertilizers 2003;(3):4–7. in Chinese with English abstract.

[41] Dong G, Dong Y, Jin J, Jin H, Liu Y. Study on the cause and development trend of desertification in the midstream region of Yarlung Zangbo River, Tibet. Journal of Desert Research 1994;14(2):9–17. in Chinese with English abstract.

[42] Witt M, Weyer K, Manning D. Designing a clean-burning, high-efficiency, dung-burning stove: lessons in cooking with cow patties. Creswell Oregon: Aprovecho Research Center; 2006.

[43] Chen R-s, Kang E-s, Ji X-b, Yang J-p, Yang Y. Cold regions in China. Cold Regions Science and Technology 2006;45(2):95–102.

[44] Tibet autonomous region Government, Tibet Autonomous Region "11th Five-Year Plan" national economic and social development plan. Lhasa: 2006, in Chinese.

[45] Chang J, Leung DYC, Wu CZ, Yuan ZH. A review on the energy production, consumption, and prospect of renewable energy in China. Renewable and Sustainable Energy Reviews 2003;7(5):453–68.

[46] Gautam R, Baral S, Herat S. Biogas as a sustainable energy source in Nepal: present status and future challenges. Renewable and Sustainable Energy Reviews 2009;13(1):248–52.

[47] Xinhuan, 150,000 Tibetans to have access to marsh gas. Xinhua News Agency, or available from: http://news.xinhuanet.com/newscenter/2008-04/05/content_7924191.htm, in Chinese.